

Integrated circuit system with a latent heat storage module

Related Applications

This application claims priority to DE Patent Application No. 10250604.3, filed October 30, 2002.

5 Field of the Invention

The present invention relates to an integrated circuit system with a latent heat storage module thermally connected to a cooling body in order to temporarily store the heat generated by the integrated circuit and to convey it to the
10 cooling body.

Background

Integrated circuit systems are often operated for a short time or intermittently at a very high power. This is
15 particularly true of power components for applications such as servo drives, soft starters, cranes and lifting or welding appliances. A cooling body is used to transfer the heat generated by high-powered operation out of the integrated circuit system. The cooling body used in high-
20 powered operating conditions is typically dimensioned in such a way that the semiconductors in the integrated circuit system are not overheated even at peak load times.

Furthermore, not only must the cooling bodies provide sufficient heat transfer to prevent exceeding the maximum

dipole layer temperature, but the cooling bodies must
ensured that the temperature does not increase to a
temperature that would adversely effect the operating life
of the integrated circuit. Accordingly, to prevent
5 shortened operating life, the cooling body must be
dimensioned even larger than would be required to transfer
the heat during peak operation to maintain the maximum
dipole layer temperature. However, in many applications,
large cooling bodies lead to problems such as weight,
10 structure size and material use.

For this reason, the short-duration peak dissipated
energy is not conventionally carried outwards directly
through a cooling body, but is temporarily stored in a heat
accumulator. A metal base plate with of sufficient thickness
15 is typically used as a heat accumulator in the case of so-
called power modules. However, this has two disadvantages.
First, the base plate is very heavy and expensive. Second,
the thermal capacity of this type of heat accumulator
depends upon the temperature increase.

20 However, it has been suggested that a latent heat
accumulator, as is shown in US 4,057,101, may provide the
same thermal capacity as a base plate heat accumulator with
a significantly lower weight. The suggested latent heat
accumulator is based on the use of a meltable material as a
25 latent heat storage medium. If a meltable material of this

kind changes its state of aggregation from solid to liquid,
this material absorbs a heat quantity which is referred to
as fusion heat. This fusion heat is released if the latent
heat storage medium solidifies again. Thus, a material with
5 a high fusion heat may be used as a heat accumulator. If
there are temperatures which are higher than the
transitional temperature of the meltable material, the heat
accumulator will maintain the transitional temperature until
such time as the entire latent heat storage material has
10 melted. Thus, a heat accumulator of this kind may provide
protection against temporary overheating by the fact that
excess heat is temporarily stored until such time as it may
be carried away. Possible materials which may be used as
latent heat storage media are shown in EP 0 402 304 A1 and
15 in EP 1 087 003 A2, for example.

A further arrangement wherein a latent heat storage
medium is used for the cooling of power semiconductor
components is shown in US 5,455,458.

The integrated circuit systems with latent heat storage
20 described above, however, suffer from certain problems. The
integrated circuit systems with latent heat storage, as
described above, can not be economical manufactured. Also,
the problem of optimal heat transmission between the
semiconductor component generating the heat and the actual
25 latent heat storage medium is not satisfactorily solved.

Summary

Thus, the object of the present invention is to show an integrated circuit system and a latent heat storage module
5 using the same, wherein the thermal contact of the integrated circuit to the latent heat storage medium is improved and, at the same time, efficient and economical manufacturability is ensured.

In an exemplary embodiment, the present invention
10 provides an integrated circuit system with a latent heat storage module, wherein the thermal contact of the integrated circuit to the latent heat storage medium is improved and, at the same time, efficient and economical manufacturability is ensured. The invention is based on the
15 basic principle of directly thermally coupling a substrate, on which a semiconductor component is assembled, to a latent heat storage module. The reliable temporary storage of peak dissipated energy thus achieved ensures that the semiconductor component is always operated in an optimal
20 temperature range. Furthermore, the latent heat storage principle has a positive effect on the lifetime of the semiconductor component as, in contrast to a conventional heat accumulator, heat storage is performed only by a change in the state of aggregation without a temperature increase.

Direct thermal coupling of the substrate to the latent heat storage module reduces the thermal resistance between the semiconductor component and the latent heat storage medium, and therefore, reduces the risk of an excessively high temperature increase. If the material used for latent heat storage is selected so as to be suitable for the application, heat storage may occur almost without temperature increase, which leads to a significantly improved lifetime of the module. Furthermore, the entire arrangement may be highly miniaturised.

In an exemplary embodiment of the invention, the substrate may be formed by a DCB (direct copper bonding) substrate. A DCB substrate of this kind should be understood to be a ceramics substrate which is coated on two sides with copper and is directly mounted on the semiconductor components. Advantages of DCB substrates include: good mechanical stability, corrosion resistance and excellent electrical insulation combined with a very good thermal conductivity. DCB substrates exhibit good stability as regards thermal alternating cycles and, furthermore, have a thermal expansion coefficient which approaches that of silicon, so that no intermediate layers to the semiconductor component are required in order to compensate for differences in thermal expansion. Finally, structuring and processing are very simple.

A particularly simple possibility of coupling the substrate to the latent heat storage module is mechanical fixing using screws. However, other mechanical mounting methods such as riveting, locking or securing using spring
5 clips may also be used.

Alternatively, joining processes such as welding, soldering and gluing have the advantage of an even lower thermal resistance.

According to one exemplary embodiment of the invention,
10 the latent heat storage module has a latent heat storage housing which forms a hollow body filled with the latent heat storage medium. This design has the advantage that the latent heat storage module may be used economically for already available standard structures as supplied by various
15 manufacturers.

According to an advantageous embodiment, a wall of the latent heat storage housing is at least partially formed by the substrate, being in thermal contact with the integrated circuit. As a result of this measure, a dividing wall
20 obstructing the thermal transmission between the semiconductor component and the latent heat storage medium is not required. Here, the substrate is in direct contact with the latent heat storage medium and may convey the heat

generated by the semiconductor component directly to the latent heat storage medium.

A substrate structure may be provided wherein the semiconductor component is assembled on a thermal coupling
5 element which is embedded in an electrically insulating frame. This solution has the advantage that the superior thermal conductivity of an electric conductor may be used for direct heat dissipation from the semiconductor element into the latent heat storage medium. In comparison to a
10 substrate manufactured as one piece from an electrically conductive material, this solution has the advantage of an electrically insulated design of the semiconductor elements in each case with a structure with a plurality of semiconductor elements as well as weight savings. Thermal
15 coupling elements of this kind may be manufactured from copper by punching and bending, for example, but other structures and other manufacturing processes may also be used. In the case of assembly of a multiplicity of semiconductor components, electrical insulation of the
20 semiconductor components from one another and with regard to the cooling body may therefore be achieved with simultaneous achievement of a high thermal capacity and thermal conduction.

A exemplary thermal coupling element of this kind may
25 have a substantially U-shaped cross-section, the

semiconductor component being assembled on the base and the two limbs being surrounded by the latent heat storage medium. "Cooling islands" designed in this way have the advantage of an optimal thermal connection to the latent
5 heat storage medium and, at the same time, permit a straightforward assembly of the semiconductor component.

According to an advantageous embodiment, the thermal coupling element may simultaneously form the electrical bulk bonding of the semiconductor component (i.e. the electrical
10 bonding of the semiconductor substrate). Using a thermal coupling element, embedded in the substrate, for both thermal coupling of the semiconductor component to the latent heat storage module and for electrical bulk bonding of the semiconductor component, simplifies assembly and
15 ensures a safe electrical bonding. In this instance, different thermal coupling elements electrically insulated from one another may be provided in each case for semiconductor components with a different bulk potential.

According to a further advantageous embodiment, a wall
20 of the latent heat storage housing, being in thermal contact with the cooling body, is at least partially formed by the cooling body itself. In this way, the latent heat storage medium is in direct thermal contact with the cooling body, and the heat stored in the latent heat storage module may be
25 carried away into the environment yet more simply. In the

alternative modular structure, the cooling body is attached to the latent heat storage module by soldering, gluing, welding or other mechanical connections.

In order to ensure a particularly rapid and efficient
5 distribution of the stored heat in the volume of the latent heat storage medium, at least one heat-conducting rib may protrude into the interior volume of the hollow body of the latent heat storage module and be thermally connected to the latent heat storage housing. A rib of this kind may be
10 formed in a particularly simple manner by a plate which is held on the latent heat storage housing in corresponding grooves.

Alternatively, the latent heat storage housing may be formed by strengthened peripheral regions of a multiplicity
15 of heat-conducting ribs arranged substantially in parallel to one another and connected to one another. Ribs of this kind may be manufactured in a very simple manner by extrusion, for example. By stacking a variable number of ribs having the same profile, high flexibility with respect
20 to the required size of the latent heat storage module may be achieved. If grooves and tongues are provided on the ribs, the individual ribs may be connected to one another in a particularly economical manner. Alternatively, however, other interlocking, non-positive or material-bonding,
25 joining techniques may also be used.

A particularly good heat-conducting and temperature-resistant manner of connection is needed for the connection between the semiconductor component and the substrate. This may be either a soldered connection or a glued connection or
5 else a press-fit connection.

Various materials whose transitional temperature lies in the temperature range which should not be exceeded during operation of the semiconductor component are suitable as latent heat storage media. A possible, economical and easily
10 manageable material in this instance is paraffin.

The electrical connections which are required on the upper side of the semiconductor component may be made depending on the type of semiconductor component by means of conventional wire-bonding connections but also by means of
15 joined connections and press-fit connections.

For an improved heat conveyance to the environment, the cooling body may have at least one cooling rib for dissipation of the heat. In order to keep the dimensions of the cooling body as small as possible, the cooling body may
20 be designed in such a way that it is connectable to a cooling circuit. A cooling circuit of this kind may be realised by a fan or else by a liquid cooling circuit. In this way, the working temperature may be kept constant even during very long intermittent periods.

Brief Description of the Drawings

The invention will be described in more detail hereinafter with reference to the embodiments shown in the accompanying drawings. Similar or corresponding details are provided with the same reference numerals in the figures, in which:

Figure 1 is an exploded sectional view of an integrated circuit system according to an exemplary embodiment of the present invention;

Figure 2 is a sectional view of an integrated circuit system according to an alternative exemplary embodiment of the present invention;

Figure 3 is a sectional view of an integrated circuit system according to another alternative exemplary embodiment of the present invention;

Figure 4 is an exploded perspective view of a partially assembled latent heat storage module according to an exemplary embodiment of the present invention;

Figure 5 is a top view of the latent heat storage module from figure 4 with the ceiling plate and or substrate removed;

Figure 6 a profile section of a latent heat storage module according to another exemplary embodiment of the present invention;

Figure 7 is a perspective view of an exemplary latent
5 heat storage module formed by profile sections as shown in Fig. 6;

Figure 8 is a perspective view of profile sections according to a further exemplary embodiment of the present invention;

10 Figure 9 is a perspective view of a further embodiment of a latent heat storage module with an integrated cooling body;

Figure 10 a is a perspective view of a further embodiment of a latent heat storage module with an
15 integrated cooling body;

Figure 11 a perspective view of the latent heat storage module from Fig. 10 with a connected fan;

Figure 12 a section through a profile section of a latent heat storage module according to a further embodiment
20 of the present invention;

Figure 13 is a perspective view of the profile section from Fig. 12;

Figure 14 is a perspective view of a profile section of a latent heat storage module according to a further exemplary embodiment of the present invention;

Figure 15 is a perspective view of a profile section of
5 a latent heat storage module according to a further exemplary embodiment of the present invention;

Figure 16 is a perspective view of a profile section of a latent heat storage module according to a further exemplary embodiment of the present invention;

10 Figure 17 is a perspective view of an assembled latent heat storage module according to a further embodiment of the present invention;

Figure 18 is a sectional view through a latent heat storage module according to a further exemplary embodiment
15 of the present invention;

Figure 19 is a sectional view of the latent heat storage module of Fig. 19 in the assembled state;

Figure 20 is a perspective view of the profile section from Fig. 18;

20 Figure 21 is another sectional view through the latent heat storage module of Fig. 18;

Figure 22 is a perspective view of a latent heat storage module according to a further embodiment of the present invention;

Figure 23 is a perspective view of a latent heat storage module with an integrated cooling body according to a further embodiment of the present invention;

Figure 24 is a sectional view through a rib structure
5 of a latent heat storage module according to a further embodiment of the present invention;

Figure 25 a an exploded perspective view of a latent heat storage module according to a further embodiment of the present invention;

10 Figure 26 is a sectional view of a latent heat storage module according to a further embodiment of the present invention;

Figure 27 is a sectional view of a latent heat storage module according to a further embodiment of the present
15 invention;

Figure 28 a sectional view, along the intersection line I-I from Fig. 29, through the integrated circuit system shown in Figure 29; and

Figure 29 is a perspective view of an integrated
20 circuit system according to a further embodiment of the present invention.

Detailed Description

Figure 1 shows an exploded sectional view of an integrated circuit system 100 according to an exemplary embodiment of the present invention. The modular structure shown here comprises the integrated circuit 102, the latent heat storage module 104, and a cooling body 106. Here, the integrated circuit 102 has a plurality of semiconductor components 108 which are assembled on a substrate 110. In the present case, the substrate 110 is formed by a so-called DCB substrate (direct copper bonding), where copper layers 114, 116 are applied onto both sides of a ceramics layer 112. A plastic housing shell 118 protectively covers the semiconductor components 108, and allows assembly of the integrated circuit 102 on the latent heat storage module 104 via the screws 120. The latent heat storage module 104 is formed by a latent heat storage housing 122 which contains the actual latent heat storage medium 124.

This latent heat storage medium 124 may be paraffin, for example. However, other media, for example, salts dissolved in liquid or metal alloys with a low melting point are also possible. In the latent heat storage module, the energy required for changing the state of aggregation of the latent heat storage medium is used for energy storage.

Because the energy required for the change of the state of aggregation corresponds to a temperature increase of from

about 50°K to about 100°K with full utilisation of the thermal capacity of a typical cooling body material, depending on the material, a substantially higher amount of energy may be temporarily stored as a result of the latent
5 heat storage principle than with the use of the thermal capacity of a cooling body material, for example of a copper plate. So that the heat to be temporarily stored may be conveyed to the latent heat storage medium 124 with as low a thermal resistance as possible, the substrate 110 of the
10 integrated circuit 102 is in direct thermal contact with the latent heat storage module 140. Heat-conducting metal ribs 126 provide improved heat distribution to the latent heat storage medium. The conveyance of the temporarily stored heat to the environment is performed in the embodiment shown
15 via a cooling body 106. The cooling body 106 corresponds to conventional metal cooling bodies and has the cooling ribs 128 required for an optimal heat conveyance. In the embodiment shown, the cooling body 106 may be configured in such a way that its heat conveyance is guided through a fan
20 or other cooling circuit. Thus the working temperature may be kept constant even during very long intermittent periods.

The cooling body 106 may be designed in such a way that without fan operation, very little heat emission occurs and the fan ensures heat conveyance from the cooling body 106
25 only during operation of the integrated circuit system 100.

Although the embodiment illustrated in Figure 1 shows the integrated circuit 102 connected to the latent heat storage module 104 by screws 120, other fastening means can also be used. For example, spring clips, rivets, catches
5 and other mounting methods may also be used for connecting the integrated circuit to the latent heat storage module.

In order to keep the thermal transmission resistances as low as possible, in addition to the modular solution shown in Fig. 1, a more complete integration of the
10 components may also be provided. For example, Fig. 2 shows an embodiment wherein the substrate 110 is connected to the latent heat storage module 104 by a soldered connection or a glued connection 130. Accordingly, a welded or bonded connection may also be provided. In this instance, the
15 cooling body 106 may also be fixed to the latent heat storage module 104 by soldering, gluing or welding. A further improved conveyance of temporarily stored heat to the cooling body may be achieved by the fact that the cooling body forms one wall of the latent heat storage
20 housing 122. Accordingly, the latent heat storage module 104 and the cooling body 106 may thus be manufactured as an integrated component.

As can be seen from the embodiment from Fig. 3, a further reduced thermal transmission resistance between the
25 heat-generating semiconductor component 108 and the latent
41132 DE - 17 -

heat storage medium 124 may be achieved in that the substrate underside, in the case of a DCB substrate, the lower copper layer 116, directly forms one of the walls of the latent heat storage housing 122. This embodiment, 5 wherein the lower copper layer 116 of the DCB substrate forms one unit with the latent heat storage housing 122, is a very good solution for upstream integrated circuits, as the load cycle values required for these applications may be achieved owing to the properties of DCB substrates. A 10 plurality of semiconductor components 108 may be assembled on a substrate 110 insulated from one another. The upper copper layer 114 of the substrate 110 may, as in the case of a printed circuit, be structured for the electrical connection of the semiconductor components 108 and, as a 15 result of the thick copper layer, a high current carrying capacity of the individual strip conductors may be achieved.

Figs. 4 to 26 show different possibilities for realising the latent heat storage module 104 shown schematically in Figs. 1 to 3. Figure 4 shows an embodiment 20 of the latent heat storage module 104 wherein the latent heat storage housing 122 is formed by various metal plates. The first metal plates 132 have grooves in which the second metal plates 134, which serve both as further housing walls and also as heat-conducting ribs 126, may be inserted. This 25 body may be closed by ceiling and floor plates 136, 138 or

else directly by the substrate 110 and the cooling body 106. Conductive plates comprising materials other than metal may also be used.

In Figure 5, a top view of the latent heat storage module structure of Fig. 4 is shown, with the two first metal plates 132 shown before assembly with the second metal plates 134 to be inserted in the grooves formed in the first plates 132. The advantage of this structure lies in the particularly simple manufacturability of the individual components, such as extrusions for first plates 132 and a rolled plate for second plates 134. In this instance, the second metal plates 134 may be soldered in, pressed in, glued in or welded in. The plates 136 and 138 may also be glued, soldered, welded or else secured by non-material-uniting joining processes.

According to a further exemplary embodiment of the invention storage module 104 may be manufactured by joining together a multiplicity of profile sections 140, as shown in Figure 6. Profile section 140 has a peripheral region 142 in which a groove 146 and a tongue 148 are arranged in such a way that a multiplicity of profile sections 140 may be arranged in series, as shown in Fig. 7, in order to form a latent heat storage module 104. The middle region 144 of the profile section 140 thus forms either one of the heat-conducting ribs 126 or else a lateral wall of the latent

heat storage housing 122. The profile section 140 may be manufactured by means of an extrusion process, for example. The connection of the individual profile sections 140 may be made by joining processes such as gluing or soldering, or
5 else by a pure interlocking fit such as press-fitting. Figure 7 also shows how, analogously to the embodiment of Figures 4 and 5, a ceiling plate 136 and a floor plate 138 close the latent heat storage housing 122. However, in this embodiment as in the modular embodiment, the substrate 110
10 and/or the cooling body 106 may directly enclose the latent heat storage medium (not shown in Figures 6 and 7), which is located in the intermediate areas 150.

Alternatively, the substrate 110 may be connected to the face 152 and, correspondingly, the cooling body 106 may
15 be connected to the face 154 formed by the peripheral regions 142 of the profile sections 150.

To increase the heat-distributing area, the profile sections 140 may, as shown in Fig. 8, be provided with additional rib structures 156 in their middle region 144. In
20 this instance, the configuration of the rib structure 156 may also be different than in the embodiment shown.

Proceeding from the embodiment shown in Fig. 7, the cooling body may be manufactured as an integral component of the latent heat storage module 104 in which the cooling ribs

using plates 136, 138, because the peripheral groove 146 and tongue 148 serve to close the portions of the latent heat storage module between adjacent profile sections.

As shown in Fig. 13, the profile sections 140 may have
5 one or more holes 162 which permit filling the spaces between profile sections 150 with the latent heat storage medium.

Similar to the embodiment shown in Fig. 8, these profile sections 140, as shown in Fig. 14, may also have
10 additional rib structures 156 to improve the heat distribution.

Fig. 15 shows a profile section 140 according to the embodiment of Fig. 12 with a formed cooling rib 128.

Similar to the embodiment shown in Figs. 10 and 11,
15 additional second tongue and groove connections 158 may also be provided to connect the cooling ribs 128 with one another. This embodiment is shown in Fig. 16.

Fig. 17 shows the arrangement of the latent heat storage module 104 with the integrated cooling body 106
20 formed from the joined profile sections 140 of Fig. 16 in a perspective view. In this instance, the face 152 designates the substrate mounting face.

The embodiments shown thus far are primarily suited for large latent heat accumulators, as the latent heat storage

module may extend below the integrated circuit to a very great depth. However, if such a depth does not have to be reached, it may be sufficient to configure only one profile section 140, which has been manufactured as a cast, pressed or deep-drawn part, as shown in Fig. 18 and to assemble the integrated circuit on the face 152. A cover plate 164, which may also be manufactured as a cast, pressed or deep-drawn part, closes the profile section 140 to the latent heat storage module 104, as shown in Fig. 19.

10 In the embodiment shown in Figs. 18 and 19, the heat-conducting ribs 126, which are formed on the profile section 140, are fitted into corresponding grooves on the ceiling section 164. This rib-groove connection ensures an improved heat flow from the substrate mounting face 152 to the cooling body side.

Figure 20 shows a perspective view of the profile section 140 according to the embodiment from Figs. 18 and 19.

As shown in Fig. 21, the ceiling section 164 may also be configured with cooling ribs 128 to form a cooling body.

Fig. 22 shows a further exemplary embodiment of the latent heat storage module 104 according to the invention. Here, the heat-conducting ribs are formed by a folded sheet metal structure 166. A cover 138 closes off the structure

towards the cooling body, while the substrate mounting face 152 may remain open, and the latent heat storage module 104 is soldered directly to the substrate to close the latent heat storage module 104.

5 A latent heat storage module 104 with an integrated cooling body 106 may be formed from two folded sheet metal plates, as shown in perspective in Fig. 23. The surface may be further enlarged by compressed ribs 166, as shown in Fig. 24, or by any other rib forms.

10 According to a further exemplary embodiment of the invention, the latent heat storage module 104 and the cooling body 106 are configured as one piece and the latent heat storage medium is located in the hollow cooling ribs 128. A cover, which closes the arrangement, serves
15 simultaneously as a substrate mounting face 152 or the closure of the latent heat storage module may be formed completely by the substrate.

As shown as examples in Figs. 26 and 27, the connection of the profile elements to one another must not compulsorily
20 be performed by means of grooves and tongues, but may be performed by any other joining processes.

Figs. 28 and 29 show an integrated circuit system 100 in a further fully-integrated embodiment. As shown in a sectional view in Fig. 28, in this embodiment, the substrate

110 is formed by electrically conductive thermal coupling elements 168 which are embedded in an electrically insulating plastic frame 170. At least one semiconductor component 108 is mounted on the thermal coupling elements 168 in each case. This may be performed by soldering, gluing or pressing techniques.

Comparable with small islands, the thermal coupling elements 168 are immersed directly into the latent heat storage medium 124 and, in this way, directly convey the heat generated by the semiconductor components 108 to the heat storage medium 124. The thermal coupling elements 168 may be manufactured from metal, preferably copper, by pressing and bending, for example. In this instance, the frame 170 ensures both a mechanical fixing as well as an electrical insulation of the thermal coupling elements 168. With respect to the embodiment shown, the substrate 110 directly forms one wall of the latent heat storage module 104. A further wall is formed by the cooling body 106. In addition to the cooling ribs 128, which ensure the heat transmission to the environment, heat-conducting ribs 126 are formed on the cooling body 106 which permit a heat distribution in the interior of the latent heat storage module 104.

With respect to the embodiment shown, the thermal coupling elements 168 realise both the electrical bulk

bonding of the semiconductor components 108 as well as their thermal coupling to the latent heat storage medium 124. For each different voltage potential at the underside of the electrical components 108, i.e. the bulk, a separate thermal coupling element 168 insulated from the other elements is required. With respect to this embodiment, the latent heat storage medium 124 has electrically insulating properties. Here, the electrical bonding of the upper side of the semiconductor component 108 may be performed by means of wire-bonding techniques, joining techniques or pressing techniques. Fig. 29 shows a perspective view of an integrated arrangement of this kind.

The highly-integrated solution shown in Figs. 28 and 29 has the advantage that expensive power substrates are no longer required. Furthermore, the thermal resistance of the insulating substrate, which is a ceramics layer in the embodiments with the DCB substrate, is avoided. Especially in applications which deliver only a short-duration but nevertheless very high power dissipation in particular, significantly higher peak loads may thus be permitted.

Furthermore, because joining techniques such as soldering on a copper plate are not required, this embodiment may offer a high load and thermal fatigue resistance. Thus, this embodiment may be advantageously used for soft-start devices to induce electric motors, frequency converters for highly

dynamic servomotors in drive technology as well as for starter generator converters in the automobile industry.